SEARCH FOR NON-RADIAL MODE AND MODULATION PHENOMENON IN GALACTIC CEPHEIDS FROM OGLE-IV SURVEY

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INTRODUCTION

Cepheids are long known variable stars, earlier known to be pulsating only in single radial modes. With progress in studies of Magellanic Clouds, this notion was recently extended and later established that they not only have presence of non-radial modes, but in some cases also show periodic modulation similar to Blazhko effect in RR Lyrae stars. So now the question was if such phenomenon is true of Galactic field Cepheids as well? If yes, is there a metallicity effect?

Our work involves a detailed search for additional low-amplitude variability phenomena such as the presence of non-radial mode or periodic modulation, in classical Cepheids of the Galactic fields. We perform frequency analysis of $\sim$2000 Galactic Cepheids using the OGLE-IV photometry database and report findings on above-mentioned phenomenon and its correspondence with Magellanic Clouds Cepheids.

The analysis employs only I-band data of the OGLE-IV survey (2010-present). The database has high-quality photometry (error of few mmag), long temporal baseline (up to 8 seasons) and high sampling rate (cadence of 19–60 min for inner Galactic bulge and 1–3 days for remaining bulge fields and Galactic disk). We employed a semi-automatic frequency analysis procedure in which we compute the Discrete Fourier Transform and identify the dominant frequencies. Subsequently, we remove 6-σ outliers in the data and also de-trend using low order polynomials. Finally, we investigate the residuals for low-amplitude signals.

RADIAL MODE DETECTION

In our sample we have detected additional periodicity that can be attributed to a radial mode. These are as follows:

- Twelve new candidates for double-mode radial pulsation were identified consisting of F+1O, 1O+2O and F+2O pulsation type.
- Six triple-mode radial candidates were detected including five F+1O+2O and one 1O+2O+3O pulsation type.

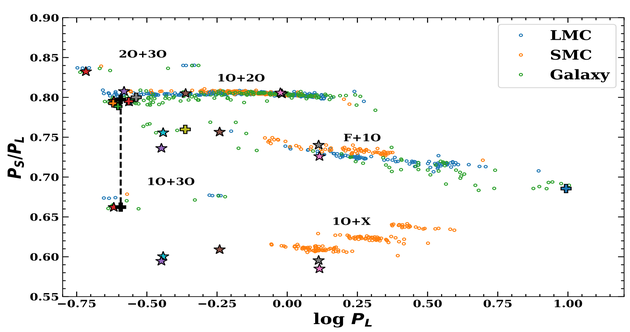

Fig. 1: Petersen diagram showing new detections of double-mode (plus symbol) and triple mode (star symbol) candidates (same colour denotes different modes for the same star). Hollow circles are OGLE-IV Cepheids from LMC (blue) SMC (orange) and Galaxy (green). Black dotted line connects the two possible double-mode solutions for OGLE-GD-CEP-1806.

NON-RADIAL MODE DETECTION

- In twelve first overtone Cepheids we detect additional low-amplitude periodicity of shorter period, corresponding period ratios, $P_x/P_{1O} \in$**(0.60, 0.65)** (marked as Group 1 in figure below). Such double-periodic Cepheids are well known in the Magellanic Clouds and form three sequences in the Petersen diagram. Comparing with Magellanic Cloud Cepheids we note that the more metal rich field, the more shifted are double-periodic stars towards longer periods. According to a model proposed by Dziembowski (2016), these additional periodicities are harmonics of non-radial modes of moderate degrees, ℓ**=7, 8 and 9**, which are easier to detect than non-radial modes themselves, as amplitudes of the latter are reduced by geometric cancellation.

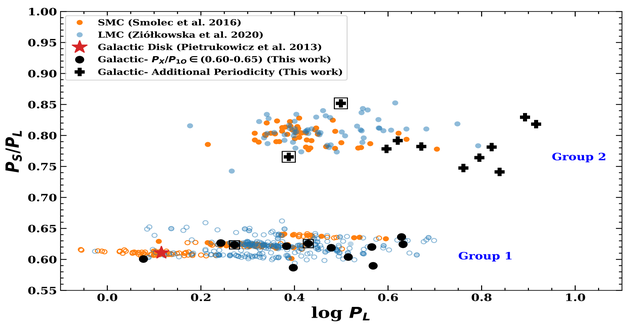

Fig. 2: Petersen diagram showing Galactic sample candidates with period ratios in the $0.60 - 0.65$ range ('Group 1'; black filled circles) and possibly, detection of sub-harmonic signal ('Group 2', black plus symbols). The symbol enclosed in black square represents Cepheids with simultaneous presence of periodicity in both groups.

- In two double-periodic stars (black enclosed square in Fig. 2) with $P_x/P_{1O} \in (0.60, 0.65)$ we detect significant signal at sub-harmonic frequency, ie., et $1/2\nu_x$. According to the model proposed by Dziembowski (2016) these signals are direct detections of non-radial modes of moderate degrees. Moreover, in nine first overtone Cepheids we detect additional variability that most likely corresponds to direct detection of the above mentioned non-radial modes, with no signature of signal at the harmonic.

MODULATION DETECTION

We report the discovery of three Cepheids with low-amplitude, periodic modulation of pulsation. Modulation was detected in single-mode F Cepheid OGLE-GD-CEP-1247, double-mode F+1O Cepheid, OGLE-BLG-CEP-095 and in single-mode, 1O Cepheid, OGLE-BLG-CEP-196. With our sample, the number of known modulated Cepheids in the Galactic fields is significantly increased. Modulation in the F+1O double-mode Cepheid is the very first detection of modulation in such combination of double-mode Cepheid pulsation. Of the two radial modes, we detect modulation of fundamental mode only. The frequency spectra for this Cepheid are shown below in Fig. 3. The pulsation and modulation periods of the detections are as follows:

- OGLE-GD-CEP-1247: P_F=3.61624(5) d and P_m=15.282(5) d
- OGLE-BLG-CEP-095: P_F=0.43329(2) d, P_{1O}=0.32924(3) d, P_m=28.5(4) d
- OGLE-BLG-CEP-196: P_{1O}=0.2535572(1) d and P_m=28.27(1) d.

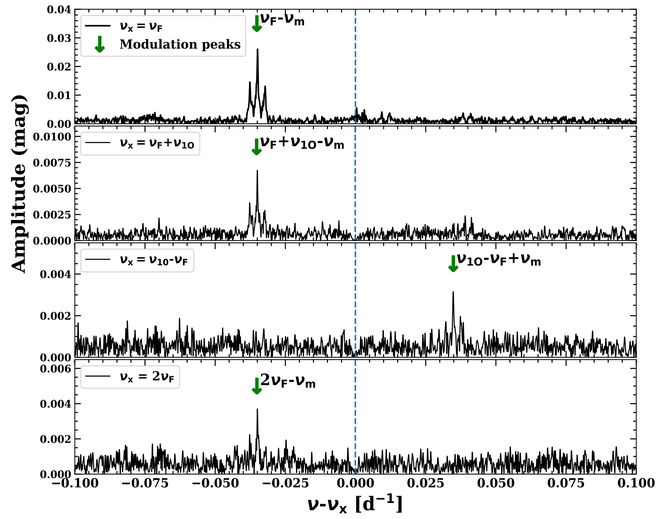

Fig. 3: Panels shows zoom in of the modulation peaks (in green) and their constant spacing with pre-whitened radial mode, its harmonic and combination frequencies (in blue).

CONCLUSION

We successfully searched for non-radial and modulation candidates in the Galactic field, thus extending the sample, with bonus of discovering twelve radial multi-mode candidates. The radial triple-mode candidates are very rare and yet very valuable assets as they are excellent laboratories for asteroseismology to test stellar evolution theory (Moskalik & Dziembowski 2005). With non-radial mode candidates in our sample and literature candidates, we comprehensively show the systematic shift in the pulsation period coupled with metallicity environment. We report three Galactic candidates with periodic modulation detected, with OGLE-BLG-CEP-095 being the first of its kind. Knowledge on whether and how these phenomena, their incidence rate and characteristics, depend on metallicity, or on a host population could be crucial for proposing and testing the models behind.

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